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Real Time Wireless Agricultural Ecosystem Monitoring for *cucumus melo .L* Cultivation in Natural Ventilated Greenhouse

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Abstract- A method for real time monitoring agricultural ecosystems is described in this paper. Soil moisture content and microclimate condition are regarded as the essential parameters in various agricultural activities such as irrigation scheduling and nutrient management. For the demand of real time monitoring soil moisture content and microclimate conditions at fertigation cultivation field, this study presents the hardware development of monitoring device that contained a microcontroller, wireless communication module, two soil moisture sensors, temperature and humidity sensors. Soil moisture sensor specifically calibrated for growing medium used in the field provides volumetric water content reading during irrigation intervals. The prototype monitoring device connected to a host personal computer, which was installed with custom made data acquisition and graphical software provided real time remote access to soil moisture, temperature and humidity in observed *cucumus melo .L* cultivation environment. Field validation tests have verified that the developed wireless monitoring can significantly improve the monitoring systems deployed in agriculture. The real time information on micro climate inside cultivation area is important for farmer to better understand plant water requirement in agricultural environments and precision agriculture operations. This could benefit two thousands fertigation farmers in the country to achieve reductions in operation cost and produce better yield.

Index Terms- real time wireless monitoring, soil moisture monitoring, volumetric water content, micro climate information

I. Introduction

The used of agricultural ecosystem or micro climate information are vital to successful farming operations in precision agriculture. Any methods used to accurately estimate plant water requirements must take the environmental and plant factors into account. Depending on the soil type, stage of crop development, and climatic conditions, a well managed agriculture field would require multiple daily irrigations to avoid water stress and yield reduction. Most farmers lack adequate sensing technology and on-the-fly data interpretation capabilities to do an effective irrigation scheduling. Existing irrigation decision support systems include the modeling approach (regional or site-specific) direct crop stress measurement and soil moisture measurements or a combination of these methods [1]-[7]. Modeling approaches use climatic data and soil water balance to predict availability of water to a crop, with an inherent weakness of reliance on the quality of its data input which may or may not incorporate any real-time site-specific measurements. Both [1] and [2] also acknowledged the importance of quality site-specific soil water hydraulic data for crop modeling. Modeling has useful predictive ability for yield, but there are limitations for real-time irrigation scheduling, where quality data which include the effects of site-specific rainfall, rooting depth and compaction zones are essential [7].

Soil moisture monitoring decision tools for irrigation on set are perhaps the most widely used. Recent advances have been made to automatically link soil moisture monitoring sites to software decision tools linked to irrigation systems [1]-[5]. Irrigation control system based on wireless sensor network (WSN) and real time agricultural ecosystem data provides a potential solution to optimize water management by remotely accessing in-field soil and climate conditions. The soil water content plays an important role in governing crop growth and yield. To monitor soil water content dynamically in the root zone, a sensor technique, which has high accuracy and reliability, rapid response, low energy consumption and cost, is desired [8],[9].

The objective of this study was to fabricate and test a wireless programming and data monitoring device that is capable of monitoring volumetric water content and climate condition in the fertigation farming facilities simultaneously. Field testing and evaluation was conducted for *cucumis melo L.* plant cultivate using fertigation method under natural ventilated green house. The wireless monitoring device will be used as part of a larger study to evaluate the optimization of irrigation management in fertigation sector in Malaysia. Other practical applications include variable rate irrigation (VRI), fertilizer dosing control and data acquisition in agricultural and aquaculture. A multiple wireless devices that integrated together to create wireless sensor network (WSN) will allow precision agriculture operations among two thousands fertigation farmers in the country to achieve reductions in operation cost and produce better yield.

II. Materials and Methods

A. Hardware Description

A wireless programmable and data monitoring device was designed around the BasicStamp 2 microcontroller (Parallax). The primary feature of the controller is capable of running a few thousand instructions per second and was programmed with simplified but customized form of Basic programming language [10]. Besides BasicStamp2 microcontroller, the other components includes flashfly wireless programming module (BlueWolf) with XBee Pro S1 wireless module (Digi) and 433 Mhz Radio frequency (RF) transceiver (Parallax). Figure 1 shows the electronic layout of entire system arranged in printed circuit board (Figure 2). The developed device main printed circuit board was designed so that all wireless components can be stacked on top of each other, minimizing the dimension of the main board to 60 mm in length and 55 mm in width. The microcontroller was assembled on top of the USB Stamp adapter board which interfaced with flashfly transceiver module.

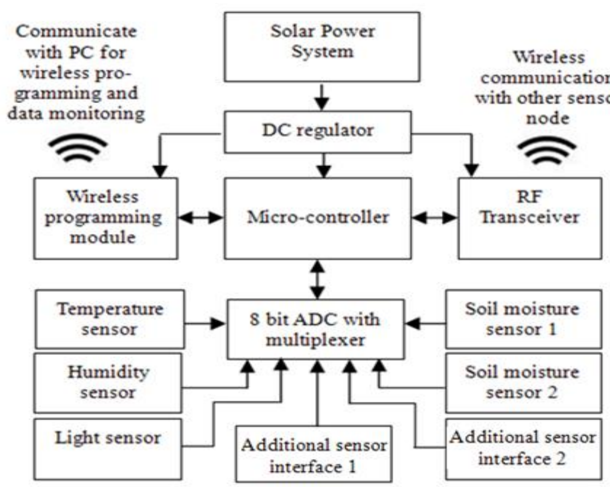


Figure 1: Layout of the electronic system for designed device

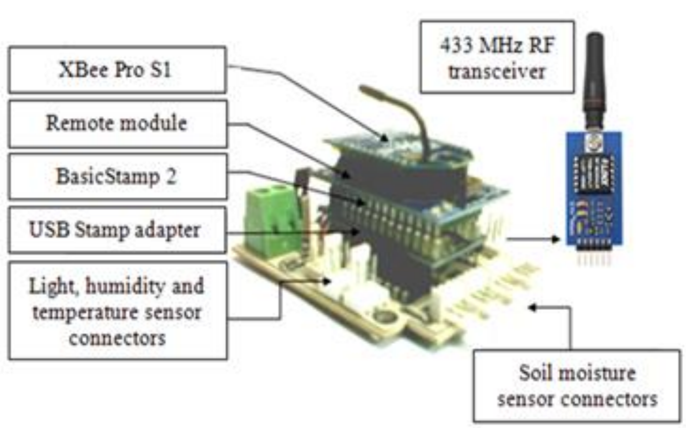


Figure 2: Electronic hardware assembly on printed circuit board

The flashfly system consists of base transceiver module and remote transceiver module. XBee Pro S1 wireless module act as wireless bridge between these two modules. Flashfly system allows wireless downloading of a program, and hence eliminates the tedious task of having to connect the system fixed platform to a computer before any programming changes can be made. This advantage and user friendly method plays a vital role during sensor calibration operations during field test validation. An 8-bit serial input/output analogue to digital converter with multiplexer (ADC0838) used to read voltage level from every sensor and send the digital values to the microcontroller for signal conditioning and unit conversion for real-time data monitoring. A 433MHz RF transceiver communicate with other wireless monitoring devices across fertigation farming area. All electronic components were assembled inside a weatherproof box. Air temperature and humidity sensors were position at the front of the electronic box to permit air exchange, and the light sensor is located on top of the electronics box. The whole unit is very compact and can be moved or installed anywhere inside the fertigation field without the need for any wiring. Power is provided by solar power system which consists of rechargeable lithium ion batteries (12V, 3800mAh), solar charge controller circuit and 1 watt solar panel. The battery is recharged by 1 watt solar panel that provides energy during daylight operation. Data is sent wirelessly to a host PC located up to 1000 meters in line of sight distance. It was a critical requirement that the device consume as little power as possible. Power consumption is minimized by putting the device into "sleep" mode between data transmissions.

The sensor nodes are provided with several integrated sensors. Temperature sensor, LM35DZ (Texas Instruments) and humidity sensor HSM20-G (Shenzen Mingjiada Electronics) provide reading for air temperature and relative humidity inside the test area [11]. Both temperature and humidity readings provides a voltage output proportional to the temperature (°C) and ambient humidity (%) and are read by the ADC0838. To achieve an acceptable accuracy of wireless monitoring system prototype, temperature and humidity sensor were calibrated using wireless weather station WS-2810 (La Crosse Technology). In this calibration procedure, raw sensor readings (i.e sensor output voltage) from sensors were fine tuned and conditioned using microcontroller program into corresponding temperature in °C and percentage of relative humidity. Plastic package CdS photocells, NORPS-12 (Silonex Incorporated) monitors the incident light intensity for day rollover and trigger the monitoring device in sleep mode for power saving [12]. An increase in light above the "night" threshold indicates that a new day has dawned. External soils moisture sensors are attached to the system to provide volumetric water content (VWC) of the soil. Advantages of soil moisture monitoring include determining soil moisture depletion, adequacy of irrigation wetting, patterns of soil moisture extraction due to root uptake of water and trends in soil with time during the irrigation season [13]. Soil moisture is determined using a specialized sensor VH400 manufactured by Vegetronix. The VH400 is a low low-power and robust soil moisture sensor. The sensor probe provides a linear voltage signal proportional to soil moisture by measures the dielectric constant of the soil using transmission line techniques [14]. The probe is insensitive to water salinity, and will not corrode over time as conductivity based probes do. The volumetric water content for coconut coir dust, growing medium used in field, was conducted inside the laboratory. Coconut coir dust or commercially known as coco peat is an agricultural by-product obtained after the extraction of fiber from the coconut husk [15]. As a growing medium, coco peat can be used to produce a number of crop species with acceptable quality in the tropics [16]. Coco peat is considered as a good growing media component with acceptable pH, electrical conductivity and other chemical attributes [15]. The VWC is defined as the volume of water per volume of bulk soil [17].

$$\theta = Vw/Vt \tag{1}$$

Eq.1 is shows the calculation of volumetric water content, θ (cm^3/cm^3). *Vw* is the volume of water (cm^3) and *Vt* is the total volume of bulk soil sample (cm^3). Using soil sampler and water lost from soil during oven drying, Eq.2 and Eq.3 shows the calculation for volume of water, *Vw*.

$$mw = mwet - mdry \tag{2}$$

$$Vw = Mw/\rho w \tag{3}$$

Where *mw* is the mass of water, *mwet* is the mass of moist soil (g), *mdry* is the mass of the dry soil, and *ρw* is the density of water ($1g/cm^3$). In addition to the volumetric water content, the bulk density of the soil sample can also be calculated using Eq.4. Bulk density, *ρb* is defined as the density of dry soil (g/cm^3).

$$\rho b = mdry \;/\; Vsoil \tag{4}$$

The output of the VH400 sensors range is between 0 V to 2.98V where 0V is when sensors are inserted in dry soil and 2.98V when inserted in the water or soil has reach maximum water holding capacity. Eq.5 to represent relationship between sensor output (*Vout*) in Volt and 8-bit ADC value.

$$ADC = Vout \;/\; (0.0195) \tag{5}$$

B. Embedded Control

The embedded control for the wireless monitoring device is written using software called BasicStamp Editor. The micro controller will perform on board sensor signal conditioning, data acquisition and communication with the host PC. The program flow chart for wireless monitoring device is given in Figure 3. Each subroutine for every sensor will read 20 sensor readings and calculate the average of 8-bit ADC value in decimal number. This is to filter and eliminate small signal fluctuations in between sensor readings. The program execution time for one cycle is 7 seconds. With 53 seconds in sleep mode, the wireless monitoring device will send data to the PC every one minute. The device will remain in sleep mode when light sensor reaches the dark threshold value to minimize power consumption.

C. Monitoring Software Description

To ensure reliable communications, the host PC is responsible for time stamping data and ensuring that wireless monitoring device is functioning correctly. Data of asynchronous 9600 baud, no parity, 8 data bits, 1 stop bit and inverted polarity that contain decimal value of air temperature, humidity and VCW for two sensors sent from wireless monitoring device to based station receiver. The base station receiver decoded the message and then sends over the USB interface to the host PC. In this application, custom made monitoring and control template using StampPlot Pro software (SelmaWare Solution) was used for data acquisition and graphical plotting for incoming data. The sample screenshots for the data acquisition and graphical plotting for incoming data from wireless sensor node are shown in Figure 4.

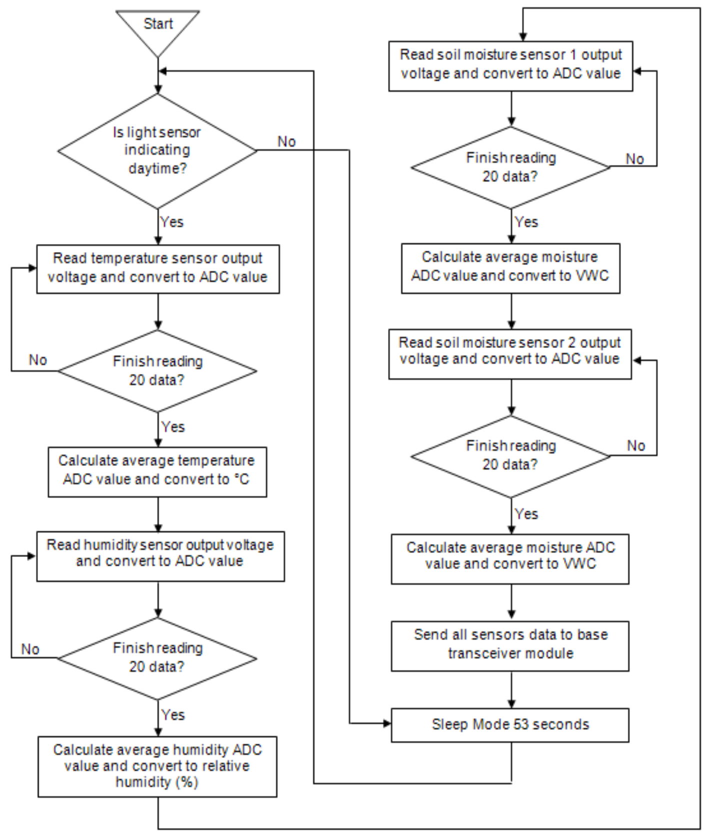


Figure 3: Program flowchart for wireless monitoring device

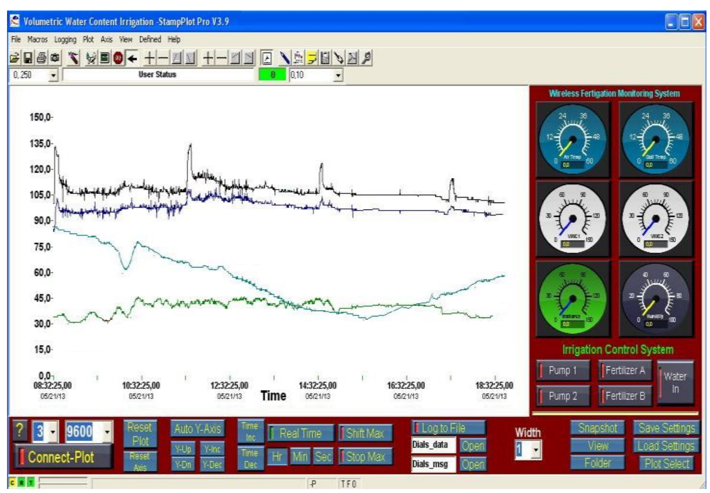


Figure 4: Screenshots for data acquisition and graphical plotting

D. Data Monitoring Testing and Validation

The field test experiment was conducted in fertigation facilities of Abi Agro Private Limited in near the town of Kangar, Perlis, Malaysia (6.47°N, 100.2°E, 15 m altitude), over a 3-week period (18^{th} May to 6^{th} June, 2013). There were 20 units of natural ventilated greenhouse with a dimension of 60 feet in length and 10 feet in width each. 2000 units of *cucumis melo L.*or locally known as rock melon were cultivated from 15^{th} April till the end of July, 2013 during the 10-week melon seasons. Figure 5 shows the rock melon plan during farming period on the test side. Rock melon is a suitable plant example planted using fertigation system in Malaysia because it was a high return and short period of growth. For rock melon grown in closed fertigation systems, desired EC is between 1.6 dS/m to 3.8 dS/m with growth period between 70 to 80 days [18]. The amount of nutrient delivered range from 500ml to 2000ml per day according to plant growth stage. Small amounts of fertilizer are used in the early stage of cultivation. Dosage is increased as fruit load and nutrient demands grow as plants approach the end of the crop's cycle. The field validation test serves as a proof of concept of the newly proposed wireless programmable monitoring system. The validation tests are intended to study the real time capabilities and the reliability of the monitoring system prototype. They were also, intended to collect and capture the spatial and temporal variability of soil moisture in between irrigation interval. The soil moisture data is vital to estimate nutrient uptake under changing ecosystems by the crops for irrigation optimization.

Figure 5: Test site for rock melon fertigation farming

III. RESULTS AND DISCUSSIONS

A. Calibration Equation of Soil Moisture Sensor

In a calibration routine conducted prior to the field validation test, coconut coir dust samples used in the fertigation farm have been dried and weighted, and pre-defined amount of water have been added. The volumetric water content calibration curves for to soil moisture (*S1* and *S2*) used in the system are shown in Fig.6. These curved were used during validation field test by wireless monitoring system to convert the voltage from sensor reading into 8-bit ADC value proportional to volumetric water content.

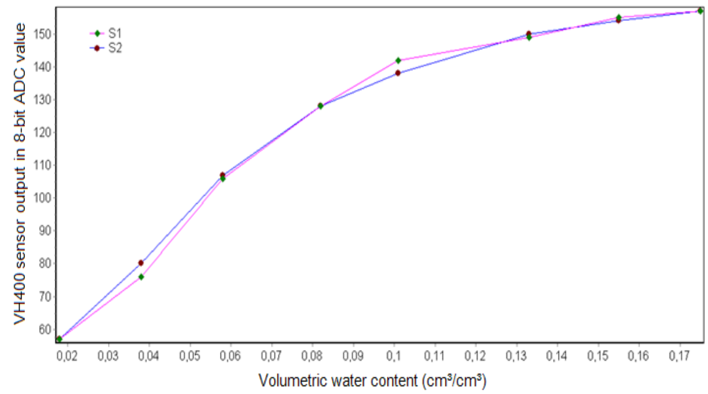


Figure 6: Calibration curves constructed for soil moisture sensor

B. Soil Moisture Monitoring

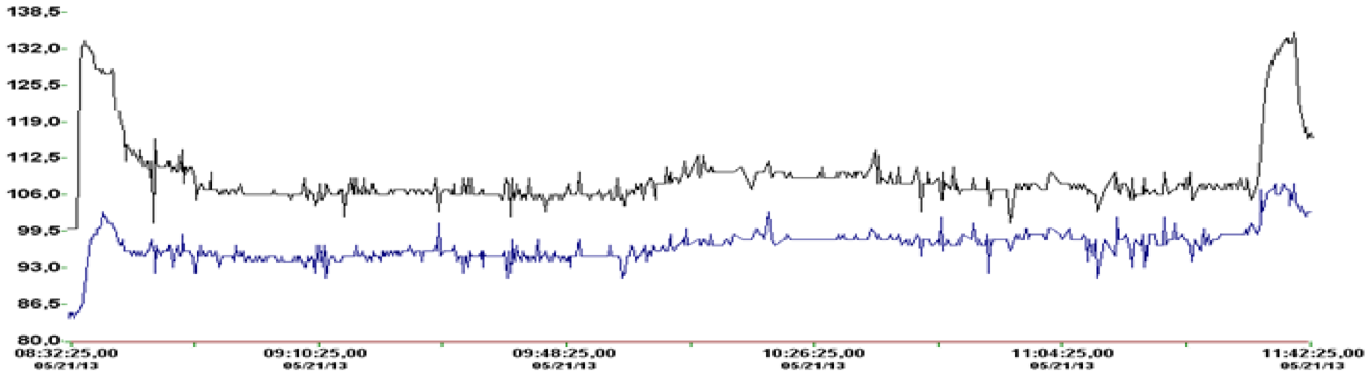
After the completion of the calibration process, the soil moisture sensors were placed in the middle of container bag representing a typical root zone of crop. As shown in Figure 7 (a), the real time of soil moisture value in VWC during irrigation period on May 21, 2013. The plant was irrigated at 8.30 am, 11.30 am, 2.30 pm and 5.30 pm during that day. In each irrigation period, a total of 350 cm^3 of nutrient injected to the plant. The immediate up rise in sensor reading in ADC value show the irrigation process has occurred. First irrigation at 8.30 am has increased the sensor reading (S1) from 84 to 95 for S1 or 0.045 to 0.05 cm^3/cm^3 in VWC index. Meanwhile another sensor (S2) shows increment of VWC from 0.057 to 0.062. The monitoring device constantly sends wireless VWC data between irrigation intervals. Figure 7 (b) shows sensors reading in the 2nd irrigation period at 11.30 am, the sensors starting to show decline trend. Both sensors have recorded an average of decline of 0.06 cm^3/cm^3 after 3 hours before third irrigation. Meanwhile during third irrigation interval between 2.30pm till 5.30pm (Figure 7(c)) the sensor has recorded minimum sensor distortion and average decline in VCW for both sensors at 0.06 cm^3/cm^3.

C. Temperature and HumidityMonitoring

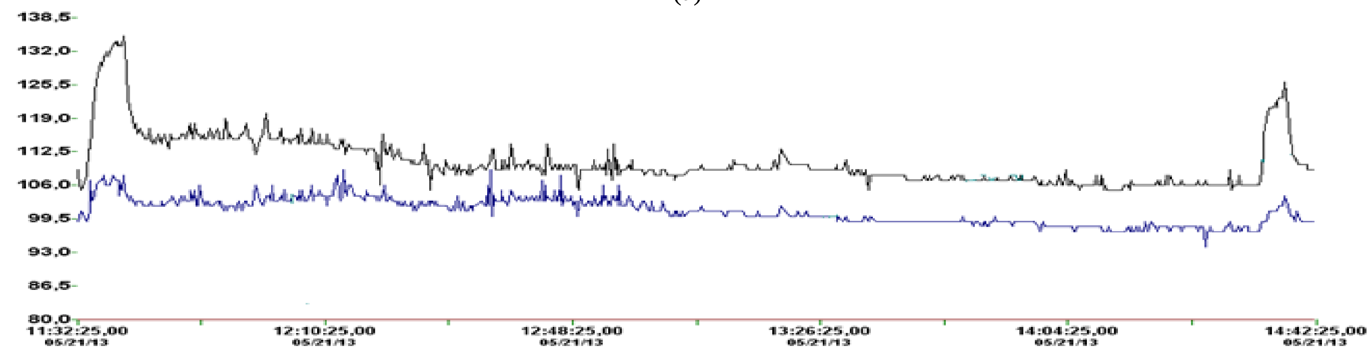
Real time temperature and humidity profile measured during May 21, 2013 has been recorded and analyzed. Figure 8 has shown the average 10 minutes data stating from 8.30 am till 5.50 pm. The average air temperature during monitoring period is 37.8°C and maximum temperature at 46.1°C. Average humidity recorded at 52.6 % and maximum and minimum at 88.2 % and 30.8% respectively. The use of clear plastic screen as a roof in natural ventilated green house result in an increase of the air temperature and humidity compared to outside the green house environment. This is mainly due to the reduction in ventilation and impaired heat removal from crop canopy and used of silver shine covering cultivation area.

IV. CONCLUSION

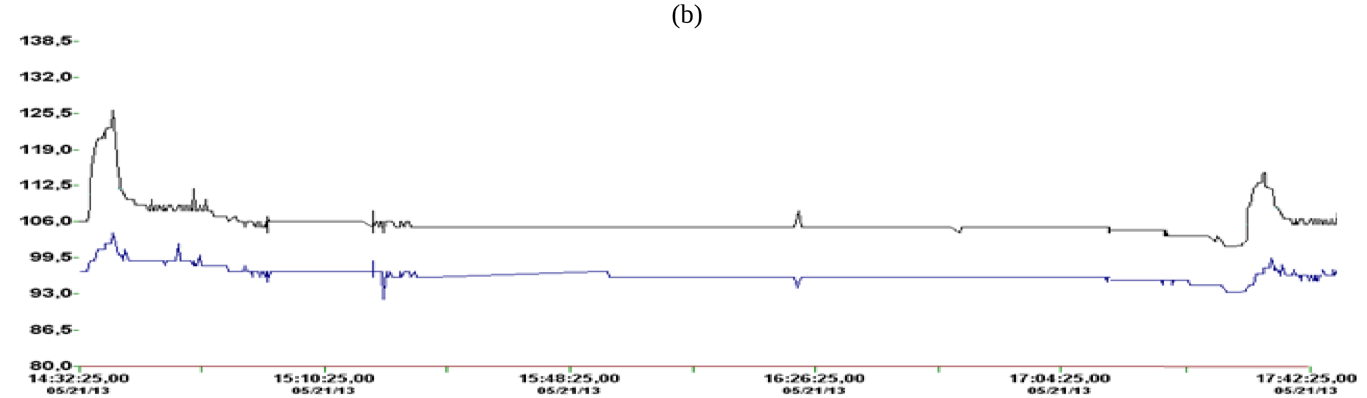
In this paper, preliminary results have been presented illustrating the design, development, the implementation and the validation of real time wireless monitoring system for agricultural ecosystems. The prototype monitoring system consist of temperature, humidity and soil moisture sensors which are wirelessly connected to host PC installed on rock melon cultivation site provide remote access to disseminate relevant soil information for scheduling irrigation planning. The real time information on micro climate is important for farmer since rock melon plant physiological is temperature sensitive. High air humidity is conducive to fungal especially downy and powdery mildew disease that commonly effected rock melon farmer in Malaysia. Nevertheless, the monitoring systems can be further improved in some respect. The current system has been designed for additional sensor interfaces such as solar radiation sensor and soil temperature sensor to better understand plant water requirement. Further field test that include several wireless monitoring devices performing wireless sensor network may be devised to further investigate the irrigation optimization potential.



(a)



(b)



(c)

Figure 7: (a) Real time sensor reading for *S1* and *S2* between 1st and 2nd irrigation interval, (b) real time sensor reading for *S1* and *S2* between 2nd and 3rd irrigation interval and, (c) real time sensor reading for *S1* and *S2* between 3rd and 4th irrigation interval

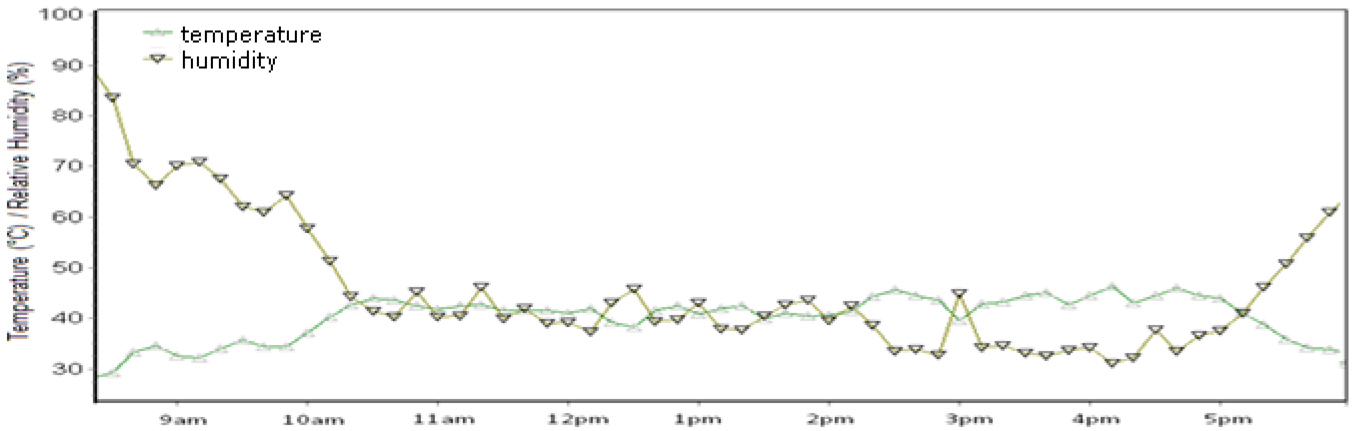


Figure 8: Average 10 minutes sensor reading on May 21, 2013

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REFERENCES

[1] DeJonge, K.C., Kaleita, A.L., Thorp, K.R., 2007. Simulating the effects of spatially variable irrigation on corn yields, costs, and revenue in Iowa. Agric. Water Manage. 92, 99–109.

[2] Humphreys, E., White, R.J.G., Smith, D.J., Godwin, D.C., 2008. Evaluation of strategies for increasing irrigation water productivity of maize in southern New South Wales using the maizeMan model. Aust. J. Exp. Agric. 48, 304–312.

[3] Green, S.R., Kirkham, M.B., Clothier, B.E., 2006. Root uptake and transpiration: from measurements and models to sustainable irrigation. Agric. Water Manage. 86, 165–176.

[4] Kim, Y., Evans, R.G., Iversen,W.M., 2008. Remote sensing and control of an irrigation system using a distributed wireless sensor network. IEEE Trans. Instrum. Meas.57 (7), 1379–1387.

[5] Peters, R.T., Evett, S.R., 2008. Automation of a centre pivot using the temperaturetime-threshold method of irrigation scheduling. J. Irrig. Drainage Eng.-ASCE 134 (3), 286–291.

[6] Vellidis, G., Tucker, M., Perry, C., Kvien, C., Bednarz, C., 2008. A real-time wireless smart sensor array for scheduling irrigation. Comput. Electron. Agric. 61, 44–50.

[7] Thompson, R.B., Gallardo, M., Valdez, L.C., Fernandez, M.D., 2007. Determination of lower limits for irrigation management using in situ assessments of apparent crop water uptake made with volumetric soil water content sensors. Agric. Water Manage. 92, 13–28.

[8] S.Nishat, Y. Guo, B.W. Baetz, 2007. Development of a simplified continuous simulation model for investigating long-term soil moisture fluctuations. Agric. Water Manage. 92, 53–63.

[9] Blonquist, J.M., Jones, S.B., Robinson, D.A., 2005. A time domain transmission sensor with TDR performance characteristics. J. Hydrol. 314, 235–245.

[10] Parallax, 2005. Basic stamp syntax and reference manual. Version 2.2. Parallax Inc. 599 Menlo Drive Rocklin, CA 95765.

[11] Shenzen Mingjiada Electronics, HSM-20G Humidity sensor module datasheet. Shenzen Mingjiada Electronics Co. Ltd. Shenzen

[12] Silonex, 2008. Plastic packaged CdS photocell datasheet. Revision 4. Silonex Inc. 5200 St. Patrick St., Montreal

[13] Hanson, B.R., Peters, D., 2000. Soil type affects accuracy of dielectric moisture sensors. Calif. Agric. 54 (3), 43–47.

[14] "Vegetronix VH400 Soil Moisture Sensor Probe", http://www.vegetronix.com/Products/VG400/ ,Vegetronix Inc., Riverton, UT,

[15] Abad, M., P. Noguera, R. Puchades, A. Maquieira and V. Noguera, 2002. Physico-chemical and chemical properties of some coconut dusts for use as a peat substitute for containerized ornamental plants. Biores. Technol., 82: 241-245.

[16] Yahya, A., H. Safie and S. Kahar, 1997. Properties of cocopeat-based growing media and their effects on two annual ornamentals. J. Trop. Agric. Food Sci., 25: 151-157.

[17] Decagon Devices, 2009. Calibrating ECH2O Soil Moisture Sensors. Application Note. Decagon Devices, Inc. 2350 NE Hopkins Court, Pullman, WA 99163.

[18] J.E Mohd Salih, A.H Adom, A.Y Md. Shakaff, 2012.Solar Powered automated fertigation control system for cucumis melo L. cultivation in green house, APCBEE procedia, 4, 79–87

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